Assimilation of Multi-Sensor Synoptic and Mesoscale Datasets An Approach Based on Statistic, Dynamic, Physical and Synoptic Considerations

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LONG-TERM GOALS

Our long-term goal is to contribute to our understanding of key elements for improving (i) the 2 to 3-day forecast of Pacific and Atlantic storms that strike the west coasts of the U. S. and Europe, and (ii) hurricane forecasts through analysis and assimilation of observations. Of particular interest to us are the combined effects of satellite data and in situ data (rawinsondes, dropsondes, buoys, ships) on the initialization of a numerical forecast model aimed at providing reliable objective forecast guidance.

OBJECTIVES

To conduct data assimilation experiments using a mesoscale forecast model and observations available during NORPEX, hurricane Bonnie, and selected squall line events over the US. We focus on one technical and one scientific objective:

1. the best use of TOMS ozone, SSM/I microwave brightness temperature and rainfall data in data assimilation
2. the role of the background auto-covariances and cross-covariances in mesoscale data assimilation (scientific goal).

APPROACH

Technical approaches involve:

1. Four-dimensional variational data assimilation (4D-Var) with the Penn/State NCAR non-hydrostatic mesoscale model version 5 (MM5).
2. Adjoint sensitivity study.

The 4D-Var experiments assess the impact of various types of data, and the adjoint sensitivity calculations provide additional insights into the key components for data assimilation and prediction.

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14. ABSTRACT
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Key individuals:

1. Drs. Zou, Xiao, and Pondeca: 4D-Var assimilation, adjoint sensitivity study, and analysis of numerical results.
2. Graduate students Mrs. Peng, Jang, Allard and Amerault: Data analysis and 4D-Var assimilation.

WORK COMPLETED

A case study of the impact of the 4D-Var assimilation of TOMS ozone data together with wind and temperature data on the prediction of cyclone associated rainfall.

Computation of background error covariances from an ensemble of perturbations.

Development of the tangent linear and adjoint operators of the NASA Goddard microphysical scheme, which are required for the assimilation of SSM/I microwave brightness temperatures.

Assessment of storm initialization using SSM/I brightness temperatures.

A case study for the impact of NCEP multi-sensor hourly rainfall data on the prediction of a squall line on 5 April 1999.

Covariance analysis of squall lines

RESULTS

1. The Impact of TOMS Ozone Data on the prediction of rainfall.

   Pondeca, M., K-I. Jang, and X. Zou, 2001: The Impact of TOMS Ozone Data on the prediction of rainfall (to be submitted during the project no cost extension).

   The 4D-Var method is being used to study the impact of TOMS ozone data on rainfall forecasts. A case study is being performed for the cyclone of January 21 and January 22, 2000, which brought intense rainfall and snowfall over the Washington DC. The MM5 control forecast initiated with the NCEP analysis failed to yield the right cyclone intensity, shape, path and rainfall amounts. The 4D-Var assimilation of TOMS ozone data had a slight positive impact on the central sea level pressure and a negligible impact on the precipitation forecast. The sole assimilation of wind and temperature data from rawinsondes stations improved remarkably the cyclone intensity, shape, path, and rainfall prediction. Contrary to our expectations, the combined assimilation of the rawinsonde data and TOMS ozone produced a slight worsening of the results for the central sea level pressure and rainfall amounts obtained when only wind and temperature data were assimilated. These results point for the need to develop auto-covariances and cross-covariances of the background errors that can effectively propagate the analysis increments gained from the assimilation of (stratospheric) ozone into the mid and lower troposphere.

2. Ensemble based background error covariance matrices

   Pondeca, M., K-I. Jang, and X. Zou, 2001: Using ensemble based background error covariance matrices to improve mesoscale 4D-Var data assimilation (in preparation).

   An ensemble based background error covariance matrix has been developed and is being tested. Using an ensemble of perturbation errors, the actual (unknown) covariance matrix is approximated with the ensemble covariance matrix B. The Lanczos algorithm is used to compute the M largest eigenvalues and corresponding eigenvectors of B, which are used to reconstruct a lower-dimension B in the space of its eigenvectors. $B^{1/2}$, which is need in the preconditioned incremental approach, is computed from the truncated eigenvector decomposition of B. The implementation of the method requires very little computer memory as only the N ensemble perturbations and the first M eigenvectors and eigenvalues need be stored. Encouraging results have been obtained for the assimilation of rawinsonde data.

3. Storm initialization using SSM/I microwave brightness temperature

   C. Amerault, K. Park, X. Zou, G.-S. Liu, and J. Hawkins: Storm initialization of Hurricane Bonnie using SSM/I brightness temperatures: Preliminary results. *The Ninth Conference on Mesoscale Processes, 30 July --- 2 August 2001, Ft. Lauderdale, Florida*.

   The skill of hurricane prediction depends strongly on the accuracy of the initial vortex. Due to the lack of observational data over the tropical oceans, where tropical storms are generated and spend most of their lifetime, the initial vortices in large scale analyses are often too weak and misplaced. Hurricane initialization, a procedure which uses limited observational data to generate a dynamically consistent and conceptually correct initial vortex of all model variables, is often needed to improve the initial storm vortex. The bogus data assimilation (BDA) scheme was found to be a promising method for initialization (Zou and Xiao 1999). BDA fits the forecast model to a set of specified bogus data such as sea level pressure (SLP) within a circular region. BDA generated fields of all model variables are dynamically and physically consistent. Furthermore, due to its variational formulation, new observations can be incorporated into BDA. Using satellite-derived water vapor wind vectors (WVWVs), rain rates, brightness temperatures, and ozone, as well as radar radial velocity and reflectivity data, a more realistic initial field can be obtained by BDA. In this study, brightness temperatures (TBs) obtained from the Special Sensor Microwave Imagery (SSM/I) are used (i) to evaluate the performance of the BDA scheme, and (ii) to improve the initial vortex of Hurricane Bonnie through direct assimilation of SSM/I brightness temperature observations.

4. The 4D-Var assimilation of multi-sensor rainfall data

   S. Q. Peng and X. Zou, 2001: Assimilation of NCEP multi-sensor hourly rainfall data using 4D-Var approach: A case study of the squall line on 5 April 1999. Submitted to *JTECH*.

NCEP multi-sensor hourly rainfall data were used for data assimilation and evaluation of quantitative precipitation forecasts (QPFs) through a case study of a squall line on 5 April 1999. Improvements in QPFs were obtained through direct assimilation of these rainfall observations using 4D-Var. Inclusion of the observed no-rain information was shown to be beneficial to QPFs. While the penalty constraint of a digital filter was effective in removing high frequency oscillations introduced by rainfall assimilation and produced a smoother ``optimal" initial condition, its impact on QPFs is mixed. Sensitivity studies indicated that the adjustments in the moisture and temperature fields that resulted from precipitation assimilation played a more important role in improving QPFs than the changes in the other state variables.

5. Covariance Analysis

Michael Allard and X. Zou, 2001: Covariance analysis and its applications to data assimilation and prediction of squall lines. (in preparation)

Spatial correlation functions have been computed for 30 squall lines that occurred during 1998-2000 over Oklahoma. The correlation functions were considerably different for T, u, v, and q, and decreased more rapidly in one direction than the others as data point separation is increased. The structures of the correlation functions are also remarkably different at different data points relative to the averaged position of squall lines. Efforts are being made to apply these structure functions for mesoscale data assimilation and also to gain insights for the planning of a future severe storm observational network.

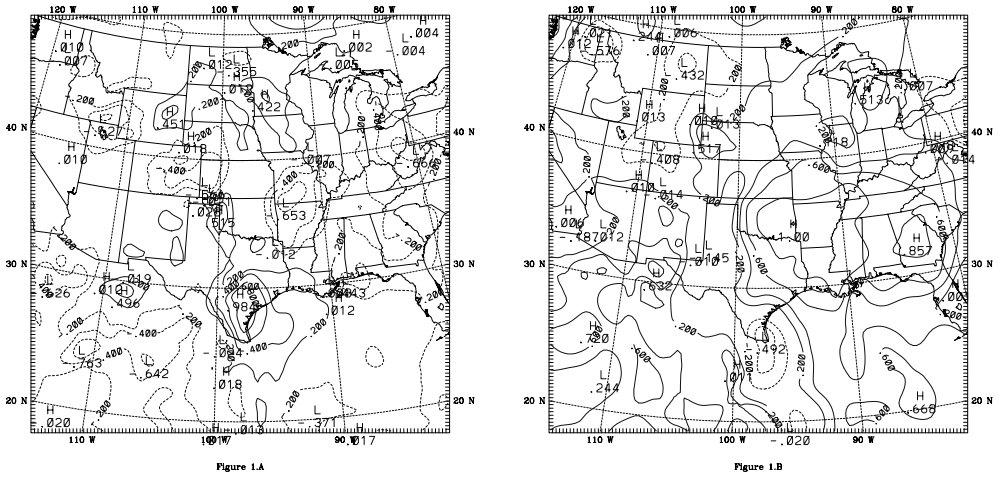

Figure 1.The autocorrelations for one point of the specific humidity, at the approximate 850 hPa level, with every other point. The autocorrelation in the left panel is calculated at time t0+12h into the forecast. The point is located in Southern Texas. The autocorrelation in the right panel is calculated at t0. This point is located in far Eastern Oklahoma. Thirteen squall lines are used for these calculations. Note the different structures in the autocorrelations.

IMPACT/APPLICATIONS

The newly developed ensemble based background error covariance matrix is expected to improve substantially the results of 4D-Var, provided that the ensemble of perturbations sample well the background errors.

The study on the 4D-Var assimilation of the NCEP multi-sensor rainfall gives a valuable contribution towards the (still open) problem of devising the best strategy for rainfall data assimilation.

TRANSITIONS

Upon finalizing the testing, the codes for the improved background error covariance matrix will be in the public domain.

RELATED PROJECTS

"Impact of radar, satellite and targeted {\it in situ} data on the hurricane forecasts near landfall", funded by NSF-USWRP under the project number ATM-9908939.

"Four-dimensional variational data assimilation and GPS data impact study using NCEP global model", funded by NSF under the project number ATM-9812729.

SUMMARY

A better understanding of the role of the background error covariances in mesoscale data assimilation has been gained. A step forward has been made towards improving the techniques for rainfall data assimilation. The ONR-sponsored work has help strengthen our Data Assimilation Group, which is a trademark of our Department.

REFERENCES

Zou, X., and Q. Xiao, 1999: Studies on the initialization and simulation of a mature hurricane using a variational bogus data assimilation scheme. *J.A.S.*, **57**, 836-860.